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THE PROBLEMS OF THE INTERNAL STRUCTURE OF THE EARTH AND OF ITS DEVELOPMENT

(Presented by Academician O. Yu. Shmidt)

The paper consists of two parts. The first part is devoted to the fundamental regularities of the development of the structure of the earth's crust, which have been established by geotectonics. In the second part (the second part of Professor Belousov's paper will be published in the next number of this journal -- The Editor) a few questions of the deep structure of the earth and of the processes within its depths are considered.

INTRODUCTION

The study of the structure of our planet and of its development represents a problem of immense scientific importance. The work in this field done by Soviet scholars should assist the development and dissemination of correct materialistic views on the nature of the earth and should destroy those unscientific, idealistic ideas on this subject which up to now have been widely propagandized by many foreign scholars. The correct illumination and elucidation of the processes taking place in the depths of the earth represents an important stage in the struggle to deepen the materialistic weltanschauung.

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The discovery of the laws that govern the structure and development of the earth's crust is of great practical significance, and is, specifically, necessary for the organized exploitation of mineral resources. It is well known that the distribution of useful minerals in the depths of the earth is governed by the processes responsible for the formation of the structure of the earth's crust. All of these exceedingly variegated processes have a common cause in the tectonic activity of the deep parts of the earth, occurring in the framework of one interrelation or the other with external factors -- in the earth's crust, the hydrosphere and the atmosphere. Up to now geology has been forced to operate mainly with a few purely empirical regularities and almost completely deprived of the possibility of fully interpreting their nature and understanding their fundamental causation, owing to the fact that even today, almost no study has been devoted to the deep parts of our planet. If geologists were only enabled to leave the sphere of very insecurely founded hypotheses when dealing with questions involving depths inaccessible to immediate observation and formulate even partial theories to explain the major processes of structural transformation of the earth's crust, they could count on significant new achievements, in the practical parts of their activity as well.

It is entirely correct to say that we are only making the very first steps today in the problem of the study of the deep structure and the general development of our planet. Our ideas about the condition of matter in the deep regions of the earth, about its properties, and about the processes which take place at subcrustal levels, are all exceedingly limited. The data even on

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the amount and shape of the enveloping shell of that core, furnished to us by seismic methods, are grossly imprecise.

Our ideas become especially shaky when we pass from the statistical picture of the structure to the questions of development. Here for the time being we have almost nothing at all but the very vaguest notions.

If we attentively acquaint ourselves, however, with all of these exceedingly complex problems, the conviction is born that this unsatisfactory state of affairs cannot by any means be considered justified, in view of the wide resources offered by hitherto unexploited methodological possibilities. These possibilities lie in the coordination and the concerted efforts of those scientific disciplines which have hitherto worked separately upon the problem in question. In fact today, notwithstanding a number of attempts, geology, geophysics, geochemistry and cosmogony have still only very weakly achieved any unification of their efforts, and, in the overwhelming majority of cases, each of them is still working for its own account and risk.

It is, however, completely obvious that by its very nature the problem of the deep structure and development of the earth is a complex one, in which progress is possible only by means of organic integration and simultaneous utilization of the methods and data of all these sciences. It can be asserted with entire confidence that if such unification takes place, very many problems, before which the individual scientific disciplines now stand helpless, can be solved, and that we shall advance to a far greater

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distance in the solution of these problems than would seem possible to many persons at the present day.

The aim of this paper is to help towards such a unification of sciences. It is written by a geologist who cannot lay claim to more than the position of a dilettante in other fields of science, but who nevertheless would like to participate actively in this unification, convinced as he is that it promises the possibility of such cardinal discoveries as will raise the entire science of earth to an entirely new level.

In the first part of this paper, a very brief summary is first of all given of those conclusions of geology -- or, more precisely, of geotectonics -- which, it seems to us, should be considered in the formulation of a more general "theory of the earth" and possibly even used as the foundation of such a theory. For to a very significant extent it is precisely the ignorance of geological data -- or its extreme oversimplification -- on the part of geophysicists and geochemists that has led to the failure of their efforts to formulate a theory of the development of the terrestrial sphere.

The second part of this paper is devoted to the discussion of certain considerations touching the possible character of the deep development of the earth. These considerations are of the nature of partial working hypotheses, designed once again to encourage the working out of a program of further joint research.

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I. THE BASIC DATA OF GEOTECTONICS

1. General Remarks

From the results of contemporary geotectonics, we must for our purpose first of all adduce the data on the slow vertical or so-called pulsating movements of the earth's crust, on the one hand, and on the magmatic phenomena in their varied manifestations, on the other. For it is precisely in these two groups of processes that the interrelation between the earth's crust and the processes taking place within the subcrustal depths of the earth is most immediately manifested.

Such deformations of rock structure as folds or faults must in the light of contemporary knowledge be considered secondary, evoked by those pressures which arise within the earth's crust in connection with its vertical movements. For this reason these deformations can be left out of consideration here.

The most fundamental results of the study of the vertical movements of the earth's crust and of magmatism are briefly summarized below. We have left almost untouched the factual material as well as the methods for its study and interpretation. Both can be found in works specially devoted to questions of geotectonics (1, 2). Here we need only take into account the fact that our conclusions are based on the observations carried out on the contemporary continents, inasmuch as the structure of the ocean bottom has only been studied to a very slight extent. But further on in this first part of thepaper we attempt to throw some light on the present state of the problem of the oceans.

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2. Fundamental Peculiarities of the Development of the Pulsating Movements of the Earth's Crust

The pulsating movements of the earth's crust consist in its exceedingly slow upheaval and subsidence, proceeding at annual velocities ranging from less than a millimeter to several centimeters. These movements occur everywhere, and are continuous. There are no places on the surface of the earth where these movements do not take place, and no interval of time in geological history has been marked by their absence.

At any given moment, in this process of pulsating movements, the surface of the earth is divided into sections which are rising and sections which are sinking. The dimensions and shapes of these sections vary over a wide range: from whole continents of irregular outline to small round and oval areas a few kilometers in diameter. The direction of the motion in the individual sections changes with the passage of time, i.e. uplift gives place to subsidence, and conversely. The amplitude of the pulsating movements is extremely varied and may reach 15 - 20 kilometers. The pulsating movements determine the distribution over the surface of the earth of regions of accumulation of sedimentary layers and of regions of denudation, and also the redistribution of these regions in the course of time.

The complexity of these fluctuating movements is one of their exceedingly essential properties; i.e. the fact that movements of different orders appear in them, superimposed one on the other. The varied orders of pulsating movements are distinguished by differences in period, amplitude and area embraced by a given uplift or subsidence.

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It follows from this complexity that every prolonged rising or sinking of the earth's crust proves to be, as it were, of zig-zag shape, complicated by supplementary pulsations. For the same reason the "absolute" expression of the motion of the earth's crust (i.e. with relation to the center of the earth) during any given time interval and at any given place is always represented by the algebraic sum of the movements of various order superimposed one upon the other.

A simple case of the composition of movements of various orders -- and one which is of extremely common occurrence -- is pictured in Figure 1. Within the region which as a whole is sinking (shown by the arrow F) there is a rising movement (shown by the arrow R) which is subordinate to the sinking movement. The "absolute" expression of the movement in zone A is determined by the relation between the more general sinking and the local rising. When the velocity of the former exceeds that of the latter, subsidence occurs in Zone A, though it is slower than in the S zones. When, on the contrary, the local uplift proves faster than the general subsidence, Zone A will rise. Observation has shown that the relation between the more general movements and the relatively localized movements changes in the course of time, with first one, and then the other, attaining the dominant position. Over a long period the only motion to maintain its sign unchanged will be the relative movement, as, for instance, the rise in A with respect to S in the example shown.

The dimensions of the sections involved in rising or sinking movements may vary exceedingly, both within the limits of

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a single order of movement, and, a fortiori, with the passage from one order to another. We observe general movements of vast areas, whole continents; these movements are complicated by motions embracing portions of continents measured in millions of square kilometers; and proceeding through graduated stages of more and more localized movements we come at last to the uplifts and subsidences of small sections, the width of which already can be measured in mere kilometers. Only a very slight amount of study has been devoted to this complex spectrum of pulsating movements, and its analysis is still in its rudimentary stages.

The available data, however, do allow the conclusion that at the very least two groups of phenomena of somewhat different nature are the expression of this process which we have designated, in sum and substance, as the process of pulsating movements of the earth's crust.

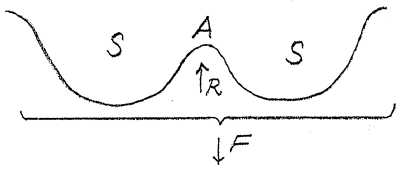

Figure 1. Example of the Composition of Tectonic Movements of Different Order.

On the one hand we observe a movement which might provisionally be termed "wave motion". It is expressed in the long-continued and slow development of upheavals and subsidences whose distribution over the surface of the earth is either stable throughout long periods of

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time, or, as is more frequently the case, is subject to a regular variation in time by means of a wave-like redistribution over the area. The conjunction of rising and sinking movements is characteristic for this group of movements. It finds expression in the fact that risings and sinkings are not independent of each other but reveal as it were a tendency to compensate each other. This means that uplifts of great velocity and great extent are accompanied by a series of equally considerable subsidences, while small and slow upheavals have a series of similarly small subsidences. With this, also, variations in the velocity of upheavals are linked with corresponding variations in the velocity of depressions in the adjacent areas.

On the other hand, there are also movements of the earth's crust which we call "general pulsations". These movements apparently embrace so extensive a territory that we can no longer speak of a conjunction of upheavals and depressions in connection with them. It is possible that entire continents undergo upheaval or depression as a result of these general pulsations.

As with the wave movements, we observe phenomena of very varying orders in the process of general pulsation. Here the different orders are distinguished as to velocity and extent of the movement. On the one hand, upheavals and depressions of whole continents are observed, with their slow emergence or submergence. On the other hand, in the history of the earth's surface, we also encounter short-term pulsations, which are fixed in the structure of the sedimentary layers, particularly in the form of short stratigraphic unconformities.

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Wave movements have a local character and manifest themselves differently in different tectonic zones. General pulsations embrace various zones, determining in each the general rhythm of the vertical movements of the earth's crust (see below) and the general stratigraphic discontinuities. Such general discontinuities of very wide and almost universal distribution include, for instance, the Pre-Upper Jurassic, the Pre-Upper Cretaceous, the Pre-Tertiary, etc.

It does not by any means follow from this that the general pulsations are everywhere of the same intensity. They embrace extensive areas, going far beyond the limits of a single geosyncline or a single platform, but in each case their intensity is very varied in different places. [The author used the transliterated word "platform" here. This has therefore been followed throughout this translation, though it is clear that what is meant is what is sometimes called a "basin" in antithesis to a geosyncline. It should be specifically noted that this use of the term "platform" does not mean a block in which the attitude of the strata is necessarily horizontal as in the current English "platform", French "massif tabulaire". -- Translator's note]

The above classification of pulsating movements into two categories was first proposed by V. Ye. Khain (3), who termed the wave movements epeirogenic, and the general pulsations oscillatory. In our own monograph, cited above (1), both these classes are referred to by the common designation of pulsating movements.

Of these two groups of vertical movements, the wave movements have been better studied; although much is still unclear in this

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field, we are today already able to speak of fundamental regularities in the development of both groups, both in time and in space. In doing so, however, we are still compelled, for the time being, to limit ourselves to movements of the very lowest orders, since the material relating to movements of higher orders still does not lend itself to generalization.

The general pulsations have been very little studied.

What regularities characterize the pulsating movements of the earth's crust in its historical development?

Among these regularities, the periodicity of the pulsating movements is the one of fundamental importance. This periodicity consists in the fact that although all over the surface of the earth areas of upheaval and areas of subsidence exist simultaneously, the general predominance periodically passes, through the course of time, from downward movements to upward movements, and back again. This periodicity of movement, which determines the periodic recurrence of marine transgressions and regressions and of sedimentary formations similar in composition, the facies of which depend upon the relations between upheavals and depressions, provides the basic landmarks of geologic history and divides it into geotectonic cycles or revolutions. At the beginning of a cycle, subsidence rules, at its close, upheaval.

The ancient, pre-Cambrian cycles are almost unknown to us, and our knowledge of tectonic history is essentially limited to its later intervals, beginning with the Cambrian. This period of time includes three geotectonic cycles: the Caledonian, the Variscian

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and the Alpine -- each of them covering about 150 million years on the average.

In the typical scheme, the Caledonian cycle begins with subsidence in Cambrian times and closes with upheaval at the end of the Silurian and the beginning of the Devonian. The Variscian cycle begins in Devonian times and closes in the Permian or the beginning of the Triassic. The Alpine cycle occupies the remaining geological time, down to the Quarternary Period.

The same cycle, however, does not always appear simultaneously at different places. In some regions a cycle may begin or end somewhat earlier, in others later. In some cases such displacements attain the dimensions of a whole geological period and even somewhat longer (30 - 40 million years, or a fifth to a quarter of the duration of each cycle). In the last, or Alpine cycle, this discrepancy is apparently greater than was the case in the Variscian and Caledonian cycles.

During the course of the last three geological cycles the earth's crust became divided into sections where greater and lesser intensity of movement prevailed -- into geosynclines and platforms.

This general periodicity of upheaval and subsidence applies to both geosynclines and to platforms. In both cases subsidence of the earth's crust takes place during the first half of the stage, and upheaval occurs during the second half. The differences consist in the amplitude, and, consequently, in the velocity of the movements: in the geosynclines both subsidence and upheaval occur on a large scale, while on the platforms these same movements are small-scale.

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It is hard to give exact figures, but we are able to estimate that as a rule the general scale of movement in the geosynclines is of the order of 15 - 20 kilometers, while it usually does not exceed 2 - 3 kilometers on the platforms.

In consequence of the great amplitude of the pulsations in the geosynclines, marine conditions dominate the first half of a cycle, while towards the end of the cycle the locality is elevated and mountainous relief is formed. Subsidence on the platforms is similarly accompanied by marine transgressions, but even after upheaval the locality, while it may emerge and become dry land, still remains lowland. In these general movements of periodic nature we see the manifestation of general pulsations of the first order.

Greater differences between the geosynclines and the platforms are observed in the development of wave movements, which occur in far more complicated fashion in the geosynclines than on the platforms.

Both geosynclines and platforms are always divided into separate zones of upheaval and subsidence. These zones are expressed with relative indistinctness on the platforms, while in the geosynclines the typical separation between trough and upheaval is extremely sharp. This sharp dissection, characterized by very close alternation between linearly elongated zones of intensive upheaval and subsidence, allows us to define the geosyncline as a region of great contrast of pulsating (wave-like) movements.

Simultaneously with the subsidence of the earth's crust in the troughs, thick sedimentary layers also accumulate there, while the

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upheavals prove to be zones of slight accumulation or even of denudation of rocks already formed. The disposition of the individual upheavals and troughs in the geosynclines does not remain unchanged throughout the course of a cycle but changes as a result of some regular process which also is of a wave-like character. In connection with these processes we may speak of primary local troughs [idiogeosynclines -- translators note] and upheavals [idiogeanticlines -- translators note] which exist within the geosyncline during the first part of the cycle, and of secondary local flexures and upheavals which develop during the second half of the geotectonic cycle.

If we refer to movements of the first order, it may be said that at the beginning of a cycle the local troughs, which are subordinated to the general subsidence of the entire geosyncline, break through with extreme intensity and expand at the expense of the primary local upheavals that separate them, while at the periphery of the geosyncline they expand at the expense of the border of the adjacent platform.

Some time later, when the subsidence has already attained considerable dimensions in the axial portions of the primary local troughs, secondary intrusions are formed, not always simultaneously. These are the so-called "central" upheavals (a phenomenon of "inversion"). Each such upheaval divides a primary trough in two. Subsequently the simultaneous process is observed: growth and expansion of the central upheaval accompanied by the outward displacement of the troughs that bound it, which troughs, when they are shifted, undergo what might be termed "rolling onto" the adjacent primary upheavals. In this process,

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the subsidence of the "marginal troughs", which bound the central upheavals and are the remnants of the primary trough, compensates, in a certain sense, the updoming of the central upheaval, both in velocity and extent, and directly depends on the latter.

The "rolling" of the marginal troughs onto the primary upheavals leads to the gradual inception of a transformation of these upheavals, starting at their margins, into zones of subsidence themselves. If this entire process proceeds far enough, and if the primary upheavals are relatively narrow, then a complete transposition in the positions of the zones of upheaval and subsidence occurs in the geosyncline towards the end of the geotectonic cycle. The central upheavals spread out and expand so that they completely occupy the place of the former primary troughs, while in the place of the primary upheavals there now appear new troughs which result from the lateral displacement of the marginal troughs: two marginal troughs, moving from opposite sides upon one and the same primary upheaval, meet, merge and are transformed into a single intramontane trough. But if the primary upheaval is wide enough, it will be attacked by the marginal troughs only at its borders, and its central portion will remain a zone of stable upheaval until the end of the geotectonic cycle (Figure 2).

At the periphery of the geosyncline, the trough, compensating the extreme central upheaval, is "rolled" upon the border of the platform and here forms a so-called advanced trough.

In consequence of the alternation of upheavals and troughs within the geosyncline at the close of a geotectonic cycle, the

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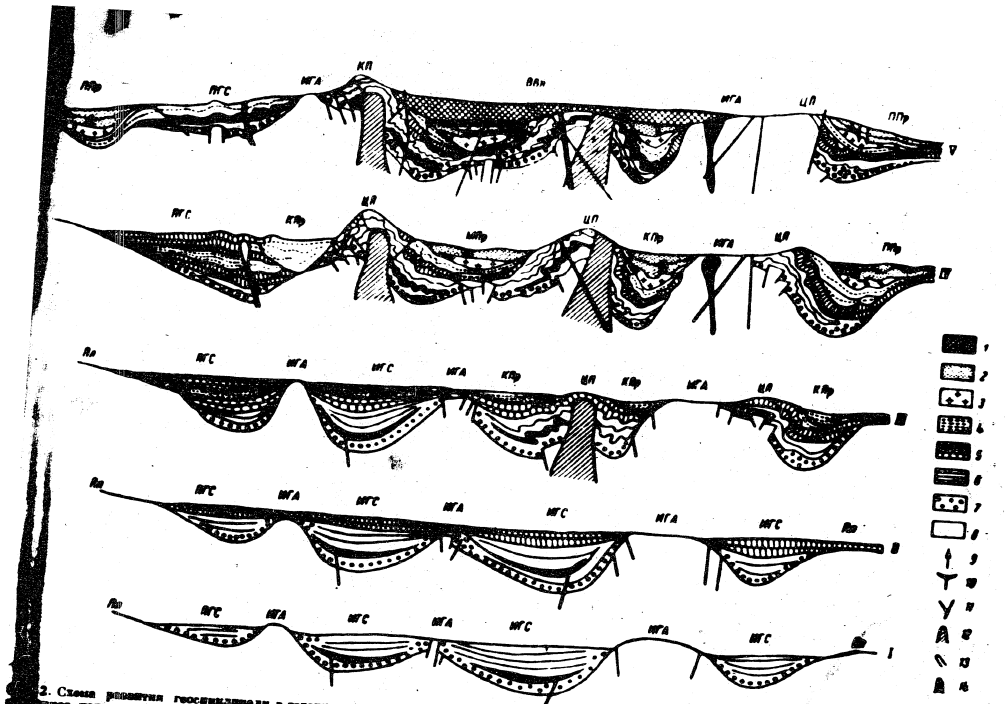

2. Схема развития геосинклинали в течение цикла: I, II, III, IV и V — стадии. *Пл* — платформа; *ИГС* — первичный прогиб; *ИГА* — ...чное поднятие; *ПГС* — парагеосинклиналь; *ЦП* — центральное вторичное поднятие; *КПр* — краевой вторичный прогиб *МПр* — ...й вторичный прогиб; *ППр* — передовой вторичный прогиб; *КП* — краевое поднятие; *ВВн* — внутренняя впадина; *1* — формация ...ских впадин; *2* — молассовая формация; *3* — лагунная формация; *4* — флишевая и каустобиолитовая формация; *5* — известия... формация; *6* — нижняя терригенная формация; *7* — конгломераты; *8* — формации предыдущих циклов; *9* — вулканы; *10* — пластовые ...интрузии и эффузии; *11* — трещинные интрузии; *12* — батолиты; *13* — малые интрузии; *14* — диапировые купола; *15* — разрывы

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Figure 2. Diagramatic Illustration of the Development a Geosyncline Throughout the Course of a Geotectonic Cycle. I, II, III, IV, V -- Stages of the cycle; ТТ = Pl -- Platform; ИГС = IGS -- Idiogeosyncline or primary trough; ИГА = IGA -- Idiogeanticline or primary upheaval; ПГС = PGS -- Parageosyncline; ЦП = CU -- Central secondary upheaval; КПр = MT -- Marginal secondary trough; МПр = IT -- Intramontane secondary trough; ППр = AT -- Advanced secondary trough; КП = MU -- Marginal upheaval; ВВ = ID -- Internal deep; 1 -- Formations of internal deeps; 2 -- Molasse formations; 3 -- Lagunal formations; 4 -- Flysch and caustobiolith formations; 5 -- Calcareous formations; 6 -- Lower terrigene formations; 7 -- Conglomerates; 8 -- Formations of preceding tectonic cycles; 9 -- volcanos; 10 -- Plastic intrusions and effusions; 11 -- Fissural intrusions; 12 -- Batholites; 13 -- Small intrusions; 14 -- Diaphyric cupola; 15 -- Faults.

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mountainous region which is formed on the site of the geosyncline is always divided into ranges and the area between them, together with the intramontane and advanced troughs that bound them on their margins. The ranges are subject to denudation, while the depressions are subject to filling up with detritus transported from the ranges.

It is easy to see that in the development of the movements we have just been describing, we actually have a picture of the wave-like development of pulsatory movements: within the wave of subsidence (the primary trough) there arises a wave of upheaval (the central upheaval). Subsequently both waves spread out and expand -- the trough with the central upheaval enclosed within it.

The process of wave-like development of troughs and upheavals proceeds with a different degree of completeness in different primary troughs and therefore leads to different results at the close of the geotectonic cycle. Where it has most fully developed, complete substitution of upheaval for trough is observed; where the process has not been so complete, we can observe only a more or less distinctly expressed central upheaval, complicating the primary trough without replacing it.

Thus in the development of wave-like movements in geosynclines the following regularities manifest themselves:

(a) the primary troughs are compounded by central upheavals, which have a tendency to push upwards and towards the sides;

(b) troughs are formed at the bases of the central upheavals,

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as if to compensate them;

(c) the primary upheavals are relatively the most stable elements, which tend to conserve their status and which are transformed into zones of subsidence only in those cases where troughs are "rolled" onto them, such troughs being linked with the occurrence of central upheavals in the adjacent primary troughs.

After the completion of one geotectonic cycle and the commencement of the next one, a region of geosynclinal conditions may remain a geosyncline and once more undergo pulsatory movements of the same pattern we have just explained.

In the course of time, however, the capacity of troughs to generate upheavals within themselves becomes weaker, and flexures which do not undergo inversion begin to appear in the geosynclines. These are the so-called parageosynclines. Their appearance already marks the transition to other geotectonic conditions, namely, to those of the platforms.

Historically the platform follows the geosyncline. Throughout the extent of the known portion of earth's history, the process of expansion of the platforms at the expense of the geosynclines has in general been observed. This process proceeds intermittently, in such a manner that at the transition from one geotectonic cycle to the following one, any territory belonging to a geosyncline ceases to form a part thereof and becomes a platform instead.

With the transition from geosynclinal conditions to platform conditions, a very substantial change in the behavior of the earth's

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crust occurs. The upheavals, which we call anteclases [not to be confounded with the "anticlases" in French, German and English which does not appear to have gained general acceptance; a "synclase" in French is a "fissure de retraite" which is a bit nearer but still not identical -- translator's note] when they occur on the platforms, and the troughs, similarly called synclases here are distinguished by far less intensity in the movements of the earth's crust than in the geosynclines, and the contrast between them is low. Yet the dimensions of the local zones of upheaval and subsidence, measured in area, increase: while in the geosynclines narrow, linear, elongated zones prevail, some tens of kilometers in width, we have to do on the platforms primarily with upheavals and flexures having indistinct rounded outlines and diameters measured in hundreds and thousands of kilometers. In contrast to the extremely fine stage of geosynclinal dissection of the earth's crust, its division in the platforms is far more coarse and far less marked by contrast.

How this takes place may be seen from a number of examples in the form of representations of the so-called internal deeps on the sites of geosynclines which have been transformed to platforms. Internal deeps are very flat and wide basins formed during the transition from geosyncline to platform and enveloping many troughs and upheavals which existed during the geosynclinal stage. The West Siberian lowland is one example of such a deep. It was formed at the beginning of the Mesozoic Era, when the Variscian geosyncline, located on this territory, was transformed to a platform. The lowland occupies the area which during the

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geosynclinal stage was exceedingly finely dissected by troughs and upheavals.

The platform zones of upheaval and subsidence, however, do not just simply replace the analogous if more contrast-marked geosynclinal zones. The interrelations between the former and the latter types are far more complex than that; it develops that the anticlases and synclases of the platforms have a much wider range of distribution; they do not merely hug the edges of the platforms but also continue on into the neighboring geosynclines, where, as it were, they "interfere" with the geosynclinal zones proper and "show through" them.

This phenomenon, which will play an important role in the conception set forth below, was first noted by N. S. Shatskiy (4), who gives two examples. The first concerns the South Russian platform and its linkage with the Caucasus. Here a few zones of upheaval and subsidence continue on within the limits of the adjacent portions of the Alpine geosyncline, manifesting themselves within the latter in the form of transverse synclinal turns. Thus the synclase of the Lower Povolzh'ya follows through in meridional direction to the south into the Caspian region and beyond -- up to the confines of the Caucasus. In the latter area it is responsible for the fact that the eastern portion of the Greater Caucasus is distinguished from the western portion by the considerably greater thickness of its Jurassic depositions, as well as by the absence of any outcroppings of older Jurassic formations. The whole of the southeastern depression of the Great Caucasus is also located along the line of this same transverse platform trough.

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To the west of this trough, which is common to both platform and geosyncline, there adjoins a platform zone of upheaval which also has a meridional direction. The Stavropol' upheaval belongs to it. But it also follows through into the Greater Caucasus and is responsible there for the main transverse anticlinal flexure at the meridian of Mineralny Vod. Still further to the west, the synclase of the Sea of Azov corresponds to the northwestern depression of the Greater Caucasus.

The second example is found in the interrelation of the Russian platform and the Urals. There is a zone of upheaval at the eastern part of the Russian platform, to which, specifically, the Ufimsk plateau belongs. This zone is not confined to the platform but extends latitudinally -- i.e., in a direction perpendicular to the Urals -- and continues into the latter, thus giving rise to the transverse geantisynclinal trough within the Ural geosyncline.

Similar examples are very numerous on all continents: the platform elevations and troughs follow through into the adjacent geosynclines, conditioning within them transverse, oblique or longitudinal troughs, constrictions, or, on the contrary, expansions of their proper zones of upheaval or subsidence.

These facts create the impression that the dissection of the platforms into synclases and anteclases is the expression of certain more deep-seated processes, which are responsible for the complex dissection of the geosynclines. These deep-seated processes also act within the geosynclines. But here they are supplemented by the influence of very active processes nearer the surface, which

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are responsible for the wave movements, in the narrow proper geosynclinal upheavals and troughs, which are often superimposed, in a totally different direction, upon the deeper and quieter movements. For this reason the latter only "shine through" in the geosynclines. But when the "top story" of the movement is taken down during the transition from geosyncline to platform, an exposed picture of more deep-seated movements appears before us. We shall revert again to the question of the possible foundations for such ideas.

The phenomenon of large-scale inversion is absent on the platforms. Small upheavals (cupola-shaped folds, swells) are formed in the synclases, and not infrequently these may even be of the same size as the predecessor troughs, but against the background of the dimensions of the synclase these cupola-shaped folds are relatively weak manifestations and only complicate the structure of the former to an insignificant extent, in no case occasioning their total transformation into regions of upheaval. It has been found in a number of cases that the movements on the platforms quiet down with the passage of time, and the cupola-shaped upheavals of the layers in the flexures of the more ancient parts of the platform are more weakly formed than in the more recent regions of the same platform. We see from this that the ability of troughs to form upheavals within themselves weakens in general with the passage of time, not only under geosynclinal conditions but under platform conditions as well.

It can be affirmed with sufficient certainty that the entire surface of the earth consisted of a geosyncline a few geotectonic

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cycles back. This means that the whole surface of the earth was very labile, and was everywhere divided with strong contrast into zones of uplift and zones of subsidence. This was the geosynclinal stage of the geologic history of the earth. Then came the transitional stage, characterized by the simultaneous existence of geosynclines and platforms with subsequent augmentation of the latter at the expense of the former.

The growth of the platforms upon the surface of the earth has been subject to a rough symmetry. Figure 3 shows this process, which, as can be seen, commences in certain regions and then in every cycle spreads out from these initial regions towards all sides. Such "nuclei of stabilization" occur in groups of four in the northern and southern hemispheres, and they are disposed approximately offsetting one against the other, giving a certain "frame-like" symmetry.

This schematic representation of the growth of the platforms is complicated, however, by the fact that, with the transition to the succeeding cycle, new portions of such platforms originate not only in the immediate vicinity of already existing platforms, but also not infrequently in separate spots within a geosyncline, which may prove to be divided into separate sections by such internal platforms. On the other hand, geosynclinal conditions sometimes persist for long periods in one area or another in the middle of a platform. Such "forgotten" geosynclines in the middle of platform, however, soon die out, but the "internal" platforms link up with great "external" platforms in consequence of the renewed expansion of the latter, and the general pattern of development is thus

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reestablished.

The gradual and irregular expansion of the platforms led to the narrowing of the geosynclines located between them, which as a result of this became transformed during the Alpine cycle into narrow meandering belts of predominantly latitudinal and meridional trends. The geosynclines of the Alpine cycle are so narrow that it would be logical to assume that a third stage -- that of prevalent platform conditions -- will soon be reached (and according to the opinion of some investigators, has already been reached). The reality, however, apparently proves to be rather more complex than such oversimplified conjectures.

Even though during the long period of geological history the development of the earth's crust has proceeded, in general, from geosynclinal to platform conditions, while the cases of the inverse transformation of platform to geosyncline were of purely local character and only represented insignificant temporary deviations from this general rule, nevertheless we observe something a little different during the very latest segment of geologic time.

Since the middle of the Tertiary Period, there has been what might be termed an "animation" throughout the extensive territories of Central Asia (including all of our Central Asia, and the foreign T'ien-Shan, Kuen-Lung and the other ranges and depressions between them) and Southern Siberia (Altay and Sayany), where geosynclinal conditions were interrupted, at some places, in Upper Paleozoic times and at some places in Lower Paleozoic times, and where, subsequently to this, platform conditions already existed for a long time (at

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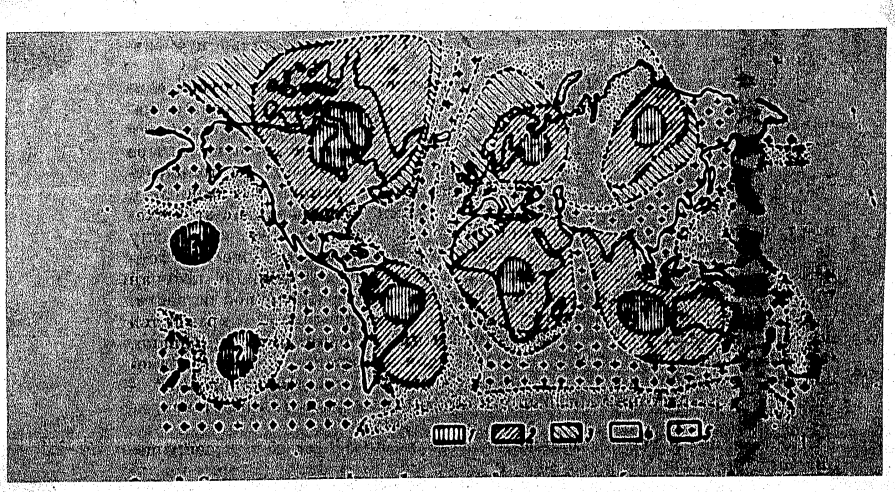
least during the Mesozoic). Here exceedingly intensive vertical movements of the earth's crust commenced anew, which attained amplitudes of over 10 kilometers during the period of time involved. The contrasting character of these movements, expressed in the close sequence of alternating uplifts and subsidences forces us to term these new conditions, from the above point of view, as similar to those in the geosynclines. We do not of course know what the future development here will be, or whether we shall have the whole complex of phenomena that is typical for geosynclines, but the conditions observed today are similar to geosynclinal ones. Thus it is possible to speak of the manifestation over a large area, in the very near future, of a special process which to some extent resembles a transformation of platform to geosyncline. The precise significance of this process in the development of the earth's crust is still unclear, but a few conjectures as to its causation will be set forth below.

We must still linger over one phenomenon which is of very substantial interest for the comprehension of the regularities in the development of crustal movements.



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Numerous data show that although uplifts, generally speaking, are more stable than subsidences, the long-term and persistent upheaval of the earth's crust will sooner or later be complicated by a movement in the opposite direction, frequently having the character of a collapse or a subsidence of the supporting arch. Such settlements, against a background of upheaval, are observed on both small and large scales. Today the regularity is well known that grabens are formed on the domes of upheavals. Thus, for instance, the system of the Rhine grabens was formed in Early Tertiary times on the arch of an extensive upheaval that continued to rise throughout all of the Mesozoic Era. The considerably greater grabens of East Africa originated at approximately the same time under analogous circumstances against a background of far more extensive anteclases.

Many anteclases are divided by faults in complicated fashion into horsts and grabens. The Baltic Shield, the Central plateau of France, and the Aldan Shield may all serve as examples. Regions of mountainous upheavals which are completing the development of their geosynclinal cycle are also subject to the appearance of subsidences. The latter are manifested in the formation, in some cases, of relatively small fault-pits, and, in other cases, of larger-scale depressions. For instance, in connection with the anticlinal uplifts of the Alpine geosynclines, which occurred mainly during the course of the Tertiary period, such internal deeps as the western part of the Mediterranean Sea or the Caribbean Sea were formed. The recent subsidences of the marginal seas of East Asia are of the same character.

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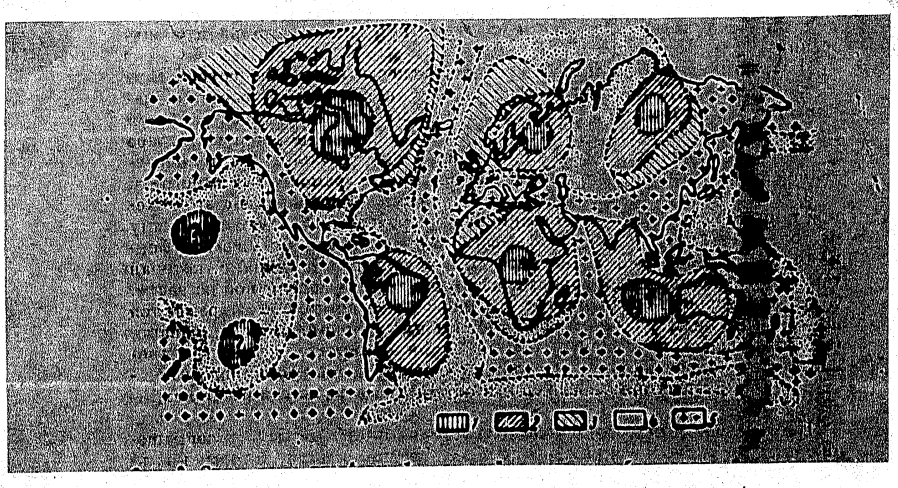

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Figure 3. Schematic Representation of the Growth of the Platforms. 1 - most ancient "nuclei of stabilization; 2 - Caledonian platforms; 3 - expansion of the platforms towards the beginning of the Variscian cycle; 4 - the same towards the beginning of the Alpine cycle; 5 - Alpine geosynclines.

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The subsidence of the parts of the earth's crust above the uplift arches is favored by the crustal fissuring which results from the tension to which it is subjected. The latter is linked with the expansion in area caused by the updoming of the crust to form the arch. For this reason the shape of the regions subject to subsidence is usually connected with the shape of the basic upheaval, inasmuch as the latter is determined by the direction of the greatest tensile forces. It would be simplest of all to view such subsidences of the arches as due to the force of gravity, which compels the submergence of any crustal block that becomes detached under tension and wedges it into the fissure being formed.

The course of the phenomenon in actual fact is more complicated. Simple wedging under the action of the force of gravity would be possible only in case the necessary empty space were freed beneath the subsiding wedge. But there can be no such empty space there, inasmuch as the dome-shaped upheaval of the crust creates a pressure from below (for instance, from the ascending current of subcrustal masses). On a small scale the subsidence is intimately linked in its physical mechanism with the formation of necks in the earth's crust under tension, when plastic deformation gives way, as it frequently does, to faulting. But another and more deep-seated mechanism must be postulated for large-scale subsidences. The very nature of this deep process which originates the domal uplifting of the earth's crust is apparently such that it regularly, in the course of time, is complicated by the reverse process of what may be described as a downward "suction" of the crust, to which those individual crustal blocks are subject which are separated by fissuring under tension.

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We shall speak below of the possible character of these processes of "suction".

We note, consequently, that both the large subsidences and the slowly developing upheavals have a tendency to be replaced by their opposite forms and, as it were, to be levelled out.

-- A few words in conclusion on the velocity of the pulsatory movements. The most rapid contemporary movements proceed at the rate of a few centimeters a year. Inasmuch as the movements are always of zigzag nature and uplifts or subsidences are continually being interrupted by movements in the opposite direction, the net average velocity in the perspective of geological time proves to be significantly less and may be reckoned in fractions of a millimeter per year.

3. The Fundamental Regularities in the Development of Magmatic Phenomena

Magmatic phenomena (magmatism) consist in the formation of heated (molten) complex silicate solutions in the depths of the earth and in their extrusion to the surface. In some cases these solutions (magmas) are discharged onto the surface in the form of lava (effusions) through fissures in the earth's crust; in other cases the magma solidifies within the earth's crust in the form of bodies of varying dimensions and shapes (intrusions).

Magmatism furnishes us with our only concrete material for judgment, based on geological observations, as to the nature of processes which originate at levels deeper than the earth's crust.

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In its development magmatism is subject to certain regularities, which, however, are known at the present time only in the most general form. Both intrusions and effusions occur in geosynclines as well as on platforms. But the intensity of magmatic phenomena in geosynclines is far greater than on the platforms, and in this connection a direct correlation is observed between magmatic activity and intensity of crustal movements.

The sequence in a geosyncline of events during the course of an orogenic revolution follows the following general pattern. At the beginning of a cycle, lava is usually extruded onto the surface in zones undergoing major subsidence. In connection with these extrusions, the lava streams alternate, in vertical cross section, with the sedimentary depositions accumulating in the same subsidence. The discharges usually commence with basic lavas. The composition of the lavas subsequently becomes less stable, and in vertical cross-section an alternation of basic lavas with neutral and acid lavas is observed. Towards the end of the subsidence, before the formation of the central upheaval, the leading position usually passes to the acid lavas. It has been noted that in this alternation of lavas of different composition the basic lavas show a tendency to be associated with more rapid subsidence of the earth's crust, while the acid lavas are more linked with epochs and localities of relative uplift.

The discharge of lavas is accompanied by the formation of basic shallow intrusions of plastic type and stock types. The time of formation and growth of the central upheavals is characterized in the magmatic process by the development of large-scale acid

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(granitic) intrusions of batholite type. These occur at about the same time as the formations of folds. At the same time the effusive activity may continue in the adjacent marginal troughs.

When a central upheaval has already undergone considerable uplift and the process of fissuring has commenced under the tensile stresses of the earth's crust, the batholite is gradually replaced by fissural intrusions of chemical composition which varies within extremely wide limits. Finally, towards the end of the cycle, during the epoch of general uplift of the geosynclines, intense effusive activity develops, which reaches its maximum values on the uplifts. At first lavas of varied composition (neutral and acid) are discharged, but subsequently the discharge takes on a stable basaltic character, and extensive ejections of basaltic lava of uniform composition are very characteristic of these epochs, which conclude an orogenic cycle.

On the margins of a geosyncline, and also in the depressions between the mountains, and on the geanticlines which have not undergone inversion, small intrusions of stock and laccolith types of neutral and alkaline composition are observed. It can in general be asserted that the intensity of the magmatic process in geosynclines is connected with the intensity of tectonic movements. Thus, the greatest discharge at the beginning of a cycle is in the zones of most intense subsidence, while at the end of a cycle it is in the places of greatest uplift. The size of the intrusions similarly corresponds, to a certain extent, to the intensity of the upheavals during which they are formed. This relation, however, is not absolute. Zones of intense subsidence are encountered in which

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the discharge was insignificant, and conversely. For instance, the subsidence in the Little Caucasus during Jurassic times was no greater than on the Great Caucasus during the same period, but the effusive activity in the former was incomparably stronger than in the latter.

As we have already noted, magmatic phenomena manifest themselves on a platform, on the whole, much more weakly and are often completely absent from very considerable territories (for example, on the Russian platform during the Alpine cycle). In places, however, they occurred with extreme intensity. Mass effusions of basalts are characteristic. These lavas, discharged during the course of a very protracted interval of time and covering extensive areas, preserve their chemical composition with amazing stability. Such, for instance, are the "traps" of Central Siberia, India, Brazil, etc. These discharges are probably connected with deep fissuring of the platforms.

Intrusions on the platforms are represented either by the fissure type or by their "small" forms (laccoliths and stocks), mainly of alkaline composition. Association of intrusions with upheavals -- anteclases and cupolas -- is observed.

4. The Structure and Development of the Oceans

In another place we have taken the position that the bathymetric method is fundamental for the study of the tectonic structure of the oceanic basins (1). In that place we also presented the general results of that study. These results may be summarized as follows.

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Inasmuch as we are now living at the very end of the Alpine cycle, our continents, at the present time, have two opposing configurations facing each other: on the one hand, the Alpine geosynclines which have just completed their development, and manifest themselves in mountainous elevations with their intramontane and marginal deeps; and on the other hand, the Alpine platforms with their anteclases and their synclases.

Both Alpine geosynclines and Alpine platforms are found to extend, together with their continents, into the oceans, while preserving all the special emphasis of their characteristic tectonic physiognomies. The difference is only in that, on the continents, the tectonic relief is smoothed out by denudation and accumulation, while on the ocean floor it maintains almost its original form.

Analysis shows, for instance, that the Central Atlantic swell represents an Alpine geosyncline in process of transformation, towards the close of the cycle, into a mountainous elevation. The character of the vulcanism in Iceland and other volcanic islands belonging to this swell confirms this conclusion. The ocean bottom on both sides of the swell represents a platform which is the continuation of the platforms located on the adjacent continents of North and South America, Africa and Europe. The deeps and prominences on the ocean bottom at these places are identical with the synclases and anteclases of the platforms.

In exactly the same way the Central Indian swell represents a mountainous elevation of the Alpine cycle, and the regions of the

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Indian Ocean to its west and its east are platforms directly connected with the continental platforms of Africa, India and Australia. The same analysis leads to the conclusion that the central portion of the Pacific Ocean, within the andesite line, is structurally an Alpine platform, and its basaltic vulcanism harmonizes well with this view.

Thus from the point of view of those pulsatory movements of the earth's crust which manifest themselves in the formation of elevations and depressions, both in geosynclines and on the platforms, the oceans are known to be no different from the continents. There is no ground for believing them to be distinguished from the latter in the peculiarities of their magmatic development: their similarity with respect to effusive magmatism is in any case entirely obvious. Consequently the same complex of tectonic and magmatic phenomena develops on the ocean floor as on the continents, only at a lower hypsometric level. The existence of these two levels -- continental and oceanic -- appears to be independent of the presence of geosynclines and platforms on the earth.

The question now arises as to the times of, and the causes for, the appearance on the earth's surface of such immense hypsometric units as the continents and the oceanic depths, and whether those groups of pulsatory movements we have been discussing up to now could not be one such cause.

We now enter the area of the extremely difficult problem of the continents and oceans -- a problem which still remains unsolved. We are by no means sure that any definite solution is yet possible

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with our present data. We express, further on in this paper, a few conjectures in this direction. And now we shall attempt to sum up what is more or less reliably known about the history of the oceanic depths and about the relation of the crustal movements in them with those on the continents.

The first thing that we must note is that up to the present moment no formations have ever been found, anywhere on the contemporary continents, which are known to have been formed in the oceanic depths. In other words, we have never found any indications of the existence, on the sites of the present continents, at any time, of deep-water oceanic basins. It is, however, true that our data in this respect goes back only to the mostrecent segment of geologic history, commencing with Paleozoic times.

If we turn now to the history of the oceanic basins, we observe a completely different picture: on the site of many regions now covered by ocean, vast tracts of dry land are known to have existed in comparatively recent times. We can observe the traces of the expansion of the ocean basins at the expense of the continents during the most recent times. This appears most clearly on the shores of the Pacific Ocean. The invasions of the northeastern, eastern and southeastern parts of Asia by the sea -- forming the Bering, Okhotsk, Japan, East China, South China and Malayan Archipelago Seas -- took place, and these resultant seas were separated from the ocean, in times that were not at all distant -- at the end of the Tertiary Period and even as late as the Quaternary (5 - 12). G. U. Lindberg found, for instance, by studying the icthyofauna, that in early Tertiary times the rivers of our Maritime

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Province fell into the ocean on the eastern shores of Japan, flowing through the dry land that then occupied the present site of the Sea of Japan (5). The Malay Archipelago was then dry land and immediately connected Asia and Australia. This tract also extended further to the east and embraced New Guinea, the Fiji Islands and New Zealand (12).

The Alaskan region is the only part of the remaining Pacific coast where there is not clear ground for supposing that even in recent times the dry land still extended into areas which are now the depths of the ocean. Such grounds exist everywhere to the south. They are especially apparent in South America, where the Andes represent only the eastern border of the extensive mountainous tract of which the greater part is now submerged beneath the waters of the ocean. The Albatross Plateau with its separate islands probably belonged to this mountainous tract;and at this point the subsidence of a vast expanse of dry land and its transformation into ocean bottom presumably occurred in very recent times, at the end of the Tertiary and even during the Quaternary Period.

It is thus possible to affirm that very recently indeed -- almost under the very eyes of Man -- the Pacific Ocean expanded with extreme vigor at the expense of the adjacent portions of the continents, which were thus, one might say, swallowed up in it together with their youthful mountain ranges.

The history of the Indian Ocean is also of interest from precisely the same point of view. The paleographic reconstructions of its site usually assume the existence of the Paleozoic continent of Gondwana, which is thought to have united South America, Africa,

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India and Australia (13). The disintegration of this continent, the subsidence of separate parts of it and their gradual transformation into oceanic basin is supposed to have commenced in Mesozoic times and to have ended as early as the Tertiary Period. We feel that the hypotheses of the existence of so immense a continent are somewhat exaggerated, inasmuch as this continent should have been broken up by at least three geosynclinal areas which existed on the present sites of the Mid-Atlantic and Mid-Indian swells. There is no doubt, however, that great continents did exist at the beginning of the Mesozoic, on the site of the hypothetical Gondwana, and that the Indian Ocean within its contemporary outlines represents a very youthful formation. Specifically the outlines of the Arabian Sea and of the eastern coast of Madagascar are determined by faults belonging to the East African system of fractures, which were formed during the Tertiary Period.

There are indications that vast tracts of dry land also existed on the present site of the Atlantic Ocean. One of them was presumably to the west of present-day Africa. The detrital material deposited in the synclinal of the Congo basin was transported from this tract (12).

There are reasons for supposing that during Tertiary times there was a large tract of dry land in the northern part of the Atlantic Ocean, to the west of Spitzbergen and Scotland (12, 13). The Hebrides Islands are apparently remnants of this tract. And it was, moreover, not earlier than the Tertiary when the Atlantic Ocean expanded its own area by linking up with the new seas: the

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Arctic and the Western Mediterranean.

At the end of the Paleozoic Era, the dry land on the western side of the North Atlantic apparently extended farther to the east of the Appalachians. The gradual subsidence of this region commenced in early Mesozoic times. We have already mentioned the recent formation of the Caribbean Sea.

The discovery during the last few decades of the submarine canyons which are everywhere cut into the continental slope at depths of 2 - 4 kilometers below the present sea level should, it would seem, prove of great significance for the decipherment of the most recent history of the oceans (6, 7, 9, 10, 14). The maximum development of these canyons was found to be in the Atlantic Ocean, but they are encountered in the other oceans as well. Up to now, however, research workers find themselves in a blind alley and at a total loss to explain this fact. If we take the most prevalent view as our starting point, which links the occurrence of submarine canyons with erosion on dry land, the following sequence of phenomena might be suggested.

Before the beginning of the last glacial epoch, the shelf had already been developed approximately in its present form and was already under water. Since the beginning of the glacial epoch, the water level of the ocean dropped by 2 to 4 kilometers, and correspondingly the continents became elevated above this level. The continental shelves thus exposed above the surface of the water were furrowed by erosional canyons, but this state of affairs lasted only a very short time, for the canyons succeeded in cutting

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only into the very border of the continental slope and left the surface of the shelf almost entirely untouched. Simultaneously with the conclusion of the glacial period, or around that time, the level of water in the oceans rose once again to approximately its previous stand, and the ocean once more flooded its shelf. The elevation of the water-level, just like the preceding fall in it, proceeded with extreme rapidity, so that neither abrasion nor sedimentary deposition could change the relief of the ocean bottom.

It has not been possible up to now to arrive at any interpretation giving the cause of these significant fluctuations in the sea level, but two interpretations would seem possible. The first one links the fluctuations with crustal movements. In this case we would have to assume that at the beginning of the Quaternary Period the continents were subjected to exceptionally powerful upheavals (of 2 to 4 kilometers) and that subsequently, at the close of the glacial epoch, they again subsided in movements of the same amplitude. The rapidity and amplitude of the crustal movements would have had to be very substantial, though not going beyond the bounds of possibility. Thus the velocity of the continental uplift would have been expressed in a movement of some centimeters a year, which velocity is even today observed in some places. This hypothesis we have hastily sketched arouses doubt from other points of view: such an agreement between the movements of all continents seems very strange, and the return to status quo after so tremendous an upheaval appears suspiciously precise. The variant proposed by D. G. Panov (8) does not appear to rebut these objections. This is to the effect that these fluctuations of sea level

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could be explained by the following sequence of events: at first the floor of the ocean subsided with respect to the continent, resulting in a fall in the level of the water; and subsequently the same subsidence drew after it the marginal portions of the continents, in consequence of which the shelf once more was submerged. Inasmuch as we can speak only of relative movements, the subsidence of the ocean floor put forward by D. G. Panov is indistinguishable from an upheaval of the continent relative to the ocean. Thus there is no fundamental distinction between Panov's scheme and the preceding hypothesis. The difference resides solely in the fact that Panov does not propose as the second event the subsidence of the whole continent, but only of its margins. This interpretation is clearly in contradiction with the facts, for if this were so, the interior portions of the continent would either have to maintain their very great elevation above sea level (up to 2 - 4 kilometers), which is not observed to be the case, or in the alternative the continents would have suddenly had to assume the shape of saucers after their elevation, with sharply uplifted margins and deeply depressed centers, which is similarly known not to have occurred.

The second interpretation attempts to link these fluctuations in ocean level with changes in the amount of water upon the terrestrial globe. In this case it is suggested that with the arrival of the glacial epoch the quantity of liquid water sharply diminished, leading to a fall in its level. With the conclusion of the glacial period the supplies of liquid water were reestablished. But such a range of variation in the quantity of water appears to be totally improbable, for in order to lower the level by 2 kilometers the

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quantity of water in the oceans would have had to be very nearly halved. Calculations show that the simple taking up of water by the glaciers during the glacial epoch could have lowered the level of water in the oceans by not more than 100 meters (12). We must also take into account that the salinity of the ocean would also fluctuate with any fluctuations in the quantity of water: it would have been doubled when the quantity of water was thus reduced and would have fallen once more when the previous level was reestablished. There are no indications of any such changes in salinity. It follows from all this that origin of the canyons by dry-land erosion is doubtful, since this point of view leads to irreconcilable contradictions.

We must also reject the view linking the canyons with submarine erosion by currents of heavier waters, loaded with silty particles. There is no proof whatever of the existence of such currents in the oceans.

The most probable of all, at the present day, appears to be the tectonic interpretation proposed by M. V. Klenova (14). This sees the canyons as yawning tectonic fissures, originating in tensile stresses and dissecting the continental slope. These fissures are presumably of recent origin, mainly during Quaternary times, when there was a simultaneous marked elevation of the continents with respect to the oceans. It can be seen at many localities on dry land that such a bursting of the continents accompanies their upheaval. For instance, the crystalline Baltic shield was broken up by fissures into numerous small blocks during the most recent -- Tertiary and Quaternary -- upheavals. Many fissures descend from

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the continent into the sea, having a radial direction with respect to the dome-shaped upheaval of the shield. This bursting of the continental masses shows their upheaval to occur under crustal tensile stresses.

The coincidence of the deepest submarine canyons with the direction of flow of the great rivers, on the dry land, can be explained by the fact that rivers make use of zones of weakening for their channels -- in this instance, of zones of fissure. On the mainland and on the shelf, however, these fissure zones were evened out by deposition and erosion, while at great depths they conserved their original yawning character. While we consider this explanation to be the most likely, we must at the same time add that this entire problem demands further study.

The question whether the quantity of water on the earth's surface has always remained substantially unchanged or whether it has undergone significant variations in the course of geological history is one of the most fundamental importance in the investigation not only of the recent history of the oceans but also of the whole history of the pulsating movements of the earth's crust.

The history of the pulsating movements on the continents does show that every tectonic cycle has ended with a general upheaval of the earth's crust and a general transformation of water areas to dry land. The question now arises: where did the water go during these epochs, which formerly covered the larger part of the continents? If the general upheaval at the close of a cycle had been linked with an increase in the volume of the earth, uniformly distributed in all

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directions, then an increase in the radius of the earth by any consistent amount that might be postulated in this connection, say 10 or 20 kilometers, would have a completely negligible effect in diminishing the depth of the oceans -- an effect which would patently be insufficient to account for the general regression from the continents. To explain this regression it is obviously necessary to assume that the crustal movements of the continents during the epochs of continental upheaval were of differential and interrelated character, during which the continents were opposed to the oceans in the sense that the continents underwent elevation relative to the oceans, as though in consequence of varying velocity of uplift or of varying direction of motion here or there. In this case the water leaving the mainland might well have found itself a place in the deepening oceanic depressions. But this conclusion may turn out to be incorrect if the quantity of water upon the earth was subject to significant variations.

As long as the question of the variability of the volume of the hydrosphere still remains open, caution must be observed in the elucidation of the history of the continents and the oceans, and only those geologic data should be used which are not open to question in this respect. Of these data we consider sufficiently well grounded those which point to the relative youthfulness of some oceanic basins or of considerable portions thereof. In general they apparently support the view that the oceans formerly occupied a smaller area, and the continents a larger, than they do at present.

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